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Crop Coefficient Based Evapotranspiration Estimates Compared with Mechanistic Model Results

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Abstract

Daily evapotranspiration (ET) estimates from reference ET (ET_R) values multiplied by a crop coefficient (K_C) have been the standard method for irrigation scheduling purposes for many years. However, curves of K_C vs. cumulative growing degree days (CGDD) or days after planting are averages of data from several individual years and the K_C value from such a curve may vary considerably from the K_C value for any given year. Mechanistic models may be more accurate but also require more data about the crop. Typically, a mechanistic model will require information about the leaf area index (LAI) and rooting depth on a daily basis to provide good ET estimates. Both the mechanistic model and the reference ET equations typically require meteorological information such as wind speed, solar radiation, air temperature, and relative humidity. We compared ET estimated using crop coefficients developed at our location for winter wheat (*Triticum aestivum L.*) with ET estimated by the mechanistic model ENWATBAL and ET measured by weighing lysimeters for three years of winter wheat grown on the southern high plains. Values of LAI were measured periodically in the field and a spline fit interpolation was used to describe the evolution of LAI on a daily basis throughout each year. In addition, a general curve of LAI vs. CGDD was developed from the data from all three years and used to parameterize ENWATBAL. For all years the ENWATBAL model using field measured LAI data gave better estimates of daily and cumulative ET than those derived from K_C and ET_R. For two of three years the ENWATBAL model using the general LAI vs. CGDD curve predicted ET better than K_C and ET_R. However, when five day cumulative ET values were compared the K_C and ET_R method gave more accurate estimates that ENWATBAL. For multiple day forecasting and irrigation scheduling the K_C and ET_R method is preferable to ENWATBAL but ENWATBAL is more useful if frequent irrigations must be made or if crop coefficients are not available.

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Introduction

Winter wheat is a major crop in the Southern High Plains. Common methods of predicting wheat water use rely on the concepts of potential or reference evapotranspiration (ET_R) and a crop coefficient (K_C) that, when multiplied by ET_R, gives an estimate of evapotranspiration (ET). The crop coefficient or basal crop coefficient (K_{CB}) may be considered to be related to number of days after planting, to cumulative growing degree days (CGDD), or to growth stage. However, use of these concepts can lead to difficulties. For example, curves of K_C or K_{CB} vs. CGDD were distinctly different for each year for three seasons of wheat at Bushland, Texas, (Howell et al., 1993). The same was true if K_C or K_{CB} were plotted vs. time to heading or vs. days after planting. The differences may be attributable to different crop growth patterns over time, and to different weather patterns which affect net radiation. Better predictions may be available from models of crop water use that include crop growth and net radiation as inputs or that accurately predict crop growth and/or net radiation. We earlier reported a model of soil and crop energy and water balances (ENWATBAL.BAS, Evett and Lascano, 1993) that gave good predictions of wheat water use (Evett et al., 1994) using a generalized function for rooting depth and density. Here we compare those predictions with those made using ET_R and K_C values. We also investigate the possibility of using a general relationship of LAI vs. CGDD to generate input data for ENWATBAL rather than using field measured LAI data.

Methods and Materials

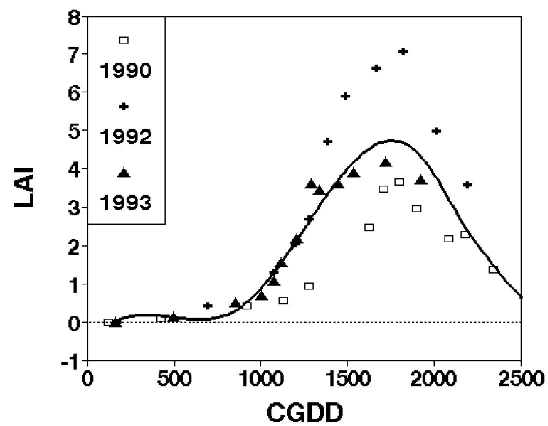
Winter wheat was grown in 1989-90, 1991-92 and 1992-93 on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) at Bushland, TX. Planting dates, crop phenology, and agronomic details were given by Howell et al. (1993) and Evett et al. (1994). Wheat was grown on two, square, 4.4 ha fields each year, one of which was well-watered. Results from only the well-watered fields will be discussed. A 3-m by 3-m square by 2.4-m deep weighing lysimeter in the center of each field measured ET (Marek et al., 1988). Irrigations were applied with a lateral move sprinkler system equipped with spray heads at about 1.5 m above ground and 1.52 m apart. A nearby (220 m to the farthest field) weather station over irrigated grass measured solar radiation, wind speed, air and dew point temperatures and barometric pressure (Dusek et al., 1987). Further details of weather station sensors, lysimeter data logging, and soil water content and temperature measurement were given by Howell et al. (1993) and Evett et al. (1994). Leaf area index was measured from whole plant samples (3 replicates each of 1 m row length) taken periodically throughout the season. Root growth was measured periodically in 1993 on a nearby well-watered wheat field as described by Evett et al. (1994).

Details of daily reference ET calculation are given by Howell et al. (1993). Briefly, ET_R was calculated for 0.5 m high alfalfa using using the Penman-Monteith equation as given in ASCE Manual 70 (Jensen et al., 1990). Daily K_C values were calculated as the ratio ET/ET_R where ET was measured by the weighing lysimeter. Growing degree days, GDD, were calculated by

$$GDD = \begin{cases} (T_u + T_{min})/2 - T_b, & T_{max} >= T_u \text{ and } T_{min} >= T_b \\ T - T_b, & T_b <= T_{max} <= T_u \text{ and } T_{min} >= T_b \\ (T_{max} + T_b)/2 - T_b, & T_b <= T_{max} <= T_u \text{ and } T_{min} <= T_b \\ 0, & T_{max} <= T_b \text{ and } T_{min} <= T_b \end{cases} \quad [1]$$

where T_u is the upper temperature threshhold taken as 26 °C, T_b is the base temperature taken as 0 °C (Ritchie, 1991), and T is the mean of the daily maximum and minimum temperatures, T_{max} and T_{min}, respectively. Cumulative growing degree days, CGDD, were calculated starting from the day of planting. A curve of K_C vs. CGDD for the data from all three years was fit with a four term Fourier series using the regression procedure of SAS, Proc REG (SAS/STAT 1987). Daily ET predictions were generated using ET_R for each day multiplied by the K_C value calculated from the Fourier series for the CGDD value for that day.

The ENWATBAL model was initialized with the average soil water contents and temperatures measured in the lysimeter on the model start day. Relationships of soil water content vs. soil water potential and soil hydraulic conductivity vs. soil water content were those used by Steiner et al. (1989). Soil albedo vs. water content, soil thermal conductivity vs. water content, and rooting depth and density over time were described by functions previously shown (Evett et al., 1994). A common function of rooting depth and density vs. day of year (DOY) was used for all model runs (Evett et al., 1994). Micrometeological input data were the half-hourly solar radiation, wind speed, and air and dew point temperatures from the weather station. Precipitation input data were developed from the weather station data and recorded depths and times of irrigation. Curves of LAI vs. DOY for each year were developed from the field LAI measurements using a combination of piecewise linear and cubic spline fitting. A general curve of LAI vs. CGDD was developed by fitting a spline curve by regression methods (Kimball, 1976) to the data from all years (Fig. 1). The model was run for each year with both that year's LAI data (model called ENW1) and again with the LAI data from the general LAI vs. CGDD curve (model called ENW2).



7-1. Leaf area index (LAI) vs. cum-ulative growing degree days (CGDD) for three years, and a general curve for LAI vs. CGDD.

Results and Discussion

The spring irrigation season for winter wheat begins in March or April at Bushland and the last irrigation before harvest occurs before DOY 160. Therefore, comparisons of estimated ET from the different methods begin at about DOY 60 and ended on DOY 160. Regression of daily estimated ET (ET_E) vs. measured ET for the three methods showed that the correlation between ET_E and ET was highest for the ENWATBAL model with LAI data from each year used in that year's model run (ENW1 in Table 1). There was some bias with all three methods indicated by regression slopes uniformly lower than unity and positive intercepts. For the years 1992 and 1993 the next highest r^2 values were for ENWATBAL using the general LAI vs. CGGD curve (ENW2), and the lowest r^2 values were for ET_E from $K_C ET_R$. For 1990 the ENWATBAL model with LAI values from the general LAI vs. CGDD curve (ENW2) gave the lowest r^2 value and overestimated cumulative ET the most. This was due to the very late increase in LAI in 1990 that was not well modeled by the general curve (Fig. 1).

Table 1. Regressions of daily estimated evapotranspiration, ET_E, vs. lysimeter measured ET in mm.

Method		r^2	Cum. ET†
	Spring 1990		
ENW1	$ET_E = 0.75 + 0.948(ET)$	0.94	449
ENW2	$ET_E = 1.90 + 0.758(ET)$	0.77	480
$K_C ET_R$	$ET_E = 0.93 + 0.930(ET)$	0.92	473
		Lysimeter ET	424
	Spring 1992		
ENW1	$ET_E = 1.09 + 0.758(ET)$	0.88	478
ENW2	$ET_E = 1.18 + 0.727(ET)$	0.85	471
$K_C ET_R$	$ET_E = 0.95 + 0.701(ET)$	0.81	442
		Lysimeter ET	508
	Spring 1993		
ENW1	$ET_E = 1.09 + 0.823(ET)$	0.94	523
ENW2	$ET_E = 1.09 + 0.828(ET)$	0.95	509
$K_C ET_R$	$ET_E = 0.19 + 0.885(ET)$	0.89	481
		Lysimeter ET	524

†Cumulative in mm.

In all years the cumulative ET was modeled best by the ENW1 model using LAI data from the particular year in question. In 1992 and 1993 the next best estimates of cumulative ET were from the ENW2 model using the general LAI vs. CGDD curve. For 1990 all models overestimated cumulative ET, and in 1992 and 1993 all models underestimated it. The closest estimates of cumulative ET were made for 1993 when the LAI vs. CGDD curve most closely approximated the actual LAI data. The 1993 season was also the most normal wheat season. The 1990 crop was hindered by winter kill and a late break of dormancy while the 1992 crop grew extremely tall and lodged.

Table 2. Regressions of 5 day cumulative estimated evapotranspiration, ET_{E5}, vs. lysimeter measured ET_5. Units are mm per 5 days.

Method		r^2	Max. Error
	Spring 1990		
ENW1	$ET_{E5} = 5.49 + 0.826(ET_5)$	0.89	12.2
ENW2	$ET_{E5} = 10.3 + 0.681(ET_5)$	0.77	13.1
$K_C ET_R$	$ET_{E5} = 3.89 + 0.955(ET_5)$	0.96	7.7
	Spring 1992		
ENW1	$ET_{E5} = 4.36 + 0.777(ET_5)$	0.80	7.3
ENW2	$ET_{E5} = 4.75 + 0.747(ET_5)$	0.76	8.7
$K_C ET_R$	$ET_{E5} = -0.08 + 0.881(ET_5)$	0.83	7.6
	Spring 1993		
ENW1	$ET_{E5} = 5.07 + 0.795(ET_5)$	0.94	6.8
ENW2	$ET_{E5} = 9.31 + 0.599(ET_5)$	0.51	15.0
$K_C ET_R$	$ET_{E5} = -2.87 + 1.033(ET_5)$	0.93	7.5

Since irrigations are often spaced several days apart so that irrigation scheduling relies on multiple day cumulative estimates of ET, it makes sense to evaluate ET estimators on the basis of cumulative ET over several days. We compared the five day cumulative estimated ET (ET_{E5}) from the three methods with the cumulative measured ET (ET_5) (Table

2). For 1990 ET_{E5} from K_C and ET_R was more accurate than that from either ENWATBAL method. The r_2 value for regression of ET_{E5} vs. ET_5 was higher and the maximum error for any five day period was lower, at 7.7 mm, than for ENWATBAL. For the 1992 and 1993 seasons the ENWATBAL method using field measured LAI values and the K_C and ET_R method gave about the same results with the former resulting in slightly lower maximum error but also slighter lower r^2 values for regressions of ET_{E5} vs. ET_5. The ENWATBAL method using the general LAI vs. CGDD curve performed the worst in all three years. This was surprising since for 1993 this method outperformed the K_C and ET_R method for estimating daily ET yet gave the largest error for ET_{E5} (15 mm). The better cumulative ET predictions from the K_C and ET_R method are due to the fact that this method was the least biased in all years with regression slopes closest to unity and intercepts closest to zero. The general conclusion drawn from these results is that while the K_C and ET_R method is less precise than ENWATBAL for daily ET estimates it is robust and more precise for five day cumulative ET. The ENWATBAL model was sensitive to LAI data and gave good estimates when LAI data specific to the year being modeled were used but did poorly when a general function of LAI vs. CGDD was used. This mechanistic model did not provide enough benefit case to encourage its use as an ET model for irrigation scheduling packages.

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